

NLTE Spectral Analysis of Central Stars of PNe Interacting with the ISM

Thomas Rauch

*Dr.-Remeis-Sternwarte, Bamberg, Universität Erlangen-Nürnberg,
Germany*

*Institut für Astronomie und Astrophysik, Universität Tübingen,
Germany*

Florian Kerber

Space Telescope - European Coordinating Facility, Garching, Germany

Elise Furlan

*Center for Radiophysics and Space Research, Cornell University, Ithaca,
NY, USA*

Klaus Werner

*Institut für Astronomie und Astrophysik, Universität Tübingen,
Germany*

Abstract. The analysis of Planetary Nebulae (PNe) provides a tool to investigate the properties of their exciting central stars (CSPN) at the moment of the PN ejection as well as on the properties of the ambient interstellar medium (ISM). The spectral analysis of the CSPN is a prerequisite to calculate the ionizing flux which is a crucial input for reliable PN modeling. In the framework of a systematic study of PNe interacting with the ISM (Kerber et al. 2000), we present preliminary results of ongoing NLTE spectral analyses of ten of their CS based on new optical medium-resolution spectra.

Recent developments in observational and deprojection techniques, spectral analysis, and numerical methods facilitate to closely examine and model PNe and their CS. These stars are at their hottest stage of evolution close to the end of nuclear burning, and gravitational effects become dominant, i.e. they display directly the formation of white dwarfs.

An indicator for their evolution is the interaction of the associated PN with the ambient ISM: the highly evolved CS is no longer dominating the processes in the PN (Kerber & Rauch 2001); the nebula displays an asymmetric brightness distribution that reflects the degree of the interaction process. These complex objects are crucial tests for our models as well as evolutionary theory.

Spectral analysis of CSPN by means of NLTE model atmosphere techniques provides information about photospheric parameters like T_{eff} , $\log g$, and surface abundances. In comparison with evolutionary calculations, we can then determine the evolutionary status, distance, mass, and luminosity of the CSPN.

Moreover, the model fluxes can be used as realistic ionizing spectra in analyses of the PNe. These allow us to obtain detailed information on the ionization structure of the nebulae, particularly in their complex interaction zones.

Table 1. Parameters of our programme stars. Detailed analyses of the CSPN of DeHt 5 and EGB 1 have been presented by Barstow et al. (2003, $T_{\text{eff}} = 58\,582\text{ K}$ and $\log g = 7.05$) and Napiwotzki (1999, $T_{\text{eff}} = 147\text{ kK}$ and $\log g = 7.34$), respectively. The CSPN of A 21 and RX J2117.1+3412 have been analyzed by Rauch & Werner (1995) and Rauch & Werner (1997), respectively. Stanghellini et al. (2002) presented Zanstra temperatures for the CSPN of NGC 6842 ($T_{\text{eff}} = 97\text{ kK}$), A 75 ($T_{\text{eff}} < 290\text{ kK}$), and NGC 6781 ($T_{\text{eff}} = 105\text{ kK}$).

name	PNG	T_{eff} / kK	$\log g$ (cgs)	H/He (mass)
DeHt 5	111.0–11.6	70	7.0	>100
EGB 1	124.0+10.4	120	8.0	>100
NGC 6842	065.9+00.5	80	5.0	4
A 75	101.8+08.7	80	6.0	0.7
NGC 6781	041.8–02.9	80	6.0	0.7
WeSb 5	058.6–05.5	80	6.0	< 4
Sn 1	013.3+32.7	100	5.0	0.4
A 52	050.4+05.2	110	6.0	0.25
A 21	205.1+14.2	140	7.5	He:C:O=35:51:14
RX J2117.1+3412	080.3–10.4	180	6.1	He:C:O=38:56:6

In July 1999, we performed medium-resolution spectroscopy of nine CSPN with the TWIN spectrograph attached to the 3.5m telescope at Calar Alto, Spain. The CS of A 21 was observed in January 1999 with EFOSC 1 at the 3.6m telescope of ESO (La Silla). Data reduction was carried out using IRAF. The observed spectra have a resolution of 2.7 \AA and S/N ratios from 10 to 30. Since the nebular emission is highly asymmetric across the projected face of these PNe, the emission cannot be subtracted perfectly. Especially in the case of Sn 1, there exists a small (about $8''$ diameter), compact inner nebula which makes a proper background subtraction impossible. However, the line wings can still be used for $\log g$ determination, and He II $\lambda 4199.8\text{ \AA}$ and He II $\lambda 4541.6\text{ \AA}$ yield information about the H/He ratio. However, the determination of T_{eff} is uncertain in such a case.

The spectral analysis is performed by means of NLTE model atmosphere techniques employing our code PR02 (Werner 1986, 1988, Werner & Dreizler 1999). The models are plane-parallel and in hydrostatic and radiative equilibrium. In general, PR02 is able to treat more than 300 individual atomic levels in NLTE with more than 1 000 individual lines (Rauch 1997, 2003)

For the classification and preliminary analysis of hot compact stars, we have set up a new grid of H+He NLTE model atmospheres with $T_{\text{eff}} = 50 - 190\text{ kK}$ (in 10 kK steps), $\log g = 5 - 9$ (in 0.5 steps) in cgs units, and H/He from pure H to pure He. With this new grid, we aim to minimize the error to about 20 kK in T_{eff} , 0.5 dex in $\log g$, and 0.5 dex in H/He. The preliminary results of our analysis

are summarized in Table 1. The grid which we used for this analysis as well as some other grids of NLTE model atmosphere fluxes with different chemical composition will be available at <http://astro.uni-tuebingen.de/~rauch>.

Within our sample of ten CSPN, whose nebulae show interaction with the ISM, our preliminary classification and spectral analysis yield two hydrogen-rich DA (pre-) white dwarfs (DeHt 5 and EGB 1 – both already known, Napiwotzki 1999), two hydrogen-deficient PG 1159 stars (A 21 and RX J2117.1+3412 – both already known, Rauch & Werner 1995), and six CS with intermediate H/He ratios (from 0.25 to 4 by mass).

Fine tuning of the parameters in the next part of this analysis will enable us to determine e.g. their spectroscopic distance reliably (cf. Napiwotzki 2001, DeHt 5: $d = 510$ pc, EGB 1: $d = 650$ pc). However, the analysis is hampered by the relatively poor seeing ($1''.6 - 2''.5$) during the observations. Further high S/N optical and UV observations with better spatial resolution would significantly reduce the error ranges.

Acknowledgements. This research was supported by the DLR under grants 50 OR 9705 5 and 50 OR 0201, and by the DFG under grants RA 733/3-1 and RA 733/14-1.

References

- Barstow, M.A., Good, S.A., Holberg, J.B., Hubeny, I., Bannister, N.P., Bruhweiler, F.C., Burleigh, M.R., Napiwotzki, R. 2003, MNRAS, 341, 870
- Kerber, F., Furlan, E., Rauch, T., & Roth, M. 2000, in: APN II: From Origins to Microstructures., eds. J.H. Kastner, N. Soker, S. Rappaport, The ASP Conference Series, Vol. 199 (San Francisco: ASP), p. 313
- Kerber, F., & Rauch, T. 2001, in: Tetons 4: Galactic Structure, Stars and the Interstellar Medium, eds. C.E. Woodward, M.D. Bica, J.M. Shull, The ASP Conference Series, Vol. 231 (San Francisco: ASP), p. 543
- Napiwotzki, R. 1999, A&A, 350, 111
- Napiwotzki, R. 2001, A&A, 367, 973
- Rauch, T. 1997, A&A, 320, 237
- Rauch, T. 2003, A&A, 403, 709
- Rauch, T., & Werner, K. 1995, in: White Dwarfs, eds. D. Koester, K. Werner, Lecture Notes in Physics 443, Springer, Berlin, p. 186
- Rauch T., Werner K. 1997, in: 3rd Conference on Faint Blue Stars, eds. A.G.D. Philip, J. Liebert, R.A. Saffer, L. Davis Press, Schenectady, NY, p. 217
- Stanghellini, L., Villaver, E., Manchando, A., Guerrero, M.A. 2002, ApJ, 576, 285
- Werner, K. 1986, A&A, 161, 177
- Werner, K. 1988, A&A, 204, 159
- Werner, K., & Dreizler, S. 1999, in: Computational Astrophysics, eds. H. Riffert, K. Werner, Journal of Computational and Applied Mathematics 109, 65